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VIRTUAL REALITY SIMULATION OF SPACE ENVIRONMENTS WITH MECHANICAL SYSTEMS

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Abstract: *This paper presents a software tool for the simulation of complex environments in space applications, including the use of Virtual Reality. The final goal of the simulation tool is to allow the realistic and real time interactive simulation of very complex space scenarios, including mechanical systems of different nature such as robots, spacecraft, floating objects, and even models of the human body.*

The tool includes a high performance visualization system, that generates a realistic 3D image of the scenario situation and system evolution, including effects such as the textures, local lights, earth reflected light, eclipse zones and sun flare. Different mechanical systems can be included in the scenario: the ERA robot, including a 3D graphic interface of its control box, inert floating objects, spacecraft, a remotely tele-operated camera, etc. A kinematic model of the human body is included in the tool, whose motion is controlled by the DYNAMAN software tool that has been connected as one mechanical simulator module more.

The software tool includes Virtual Reality techniques, based on the use of a helmet mounted display and a joystick box to create an immersive user interface. From within it, it is possible to move inside the scenario and to interact with it. As an alternative to the fully immersive interface, the tool also includes a stereo representation of the 3D scenario on the computer screen.

The paper includes a description of some scenarios that can be simulated, including a model of the International Space Station, the ERA robot evolving on it, a human model in EVA and the tele-operated camera.

1 INTRODUCTION

Simulation is becoming one of the most used techniques to help the design of mechanical systems, and some industries are using it extensively to shorten the product design cycle, as it is the case in the automotive and robotics industries[1,2].

The use of real time simulation and visualization is not traditionally associated with early phases of spacecraft design, but it has become increasingly clear that there is a potential to be exploited in this area. In this line the work presented here attempts at showing the added value that real time visual simulation can provide for the simulation of complex environments that include mechanical systems of different nature.

Current trends in simulation are oriented to three different aspects: first is visual simulation, this is, simulate the behaviour of a system and at the same time visualise its motion on the computer screen using a realistic graphical representation. Second is real time simulation, which tries to compute the system response using the same time as the real system would require: this allows the user to interact with the simulation software and to have instantaneous feedback of the system response. The third line where simulation tools are being developed is the simulation of mixed systems, including in addition to the mechanical part, other devices such as electric or electronic components, control systems, etc.

The concepts that are studied and implemented in the present work are derived from the concept of designer immersion in the design, by using Virtual Reality techniques. These concepts can be detailed in:

Interactive design: on line setting of model parameters of the simulated design, without leaving the simulation session.

Incremental fidelity: the ability to define and add increasing levels of fidelity in the simulation environment, and being able to compare the response obtained with different fidelities.

Assisted analysis: the capability of directly evaluating the performance of the simulated system by directly carrying out some measurements of its response, from within the simulation environment.

2 SIMULATION TOOL ARCHITECTURE

The simulation tool is based on client-server architecture, made up of different modules (figure 1). The central core of the server is a real time control module[3] that controls the activity of the other modules, manages the data flow among them, synchronizes their activity with the computer clock, and provides access to shared memory areas. The control system also provides basic functions such as earth motion, sun motion, ground track, etc. Other important components of the server are the high performance graphic rendering module and the associated geometry data base.

The mechanical systems included in the simulation scenario are associated to different client processes. Each client is in charge of generating the motion of a particular mechanical system.

The communication between the server and the client modules is based on a standard data interface. It is implemented using shared memory and allows using any other mechanical simulation tool that adheres to its architecture. In fact it is possible to use simultaneously any number of mechanical systems, limited only by the available hardware and the required performance.

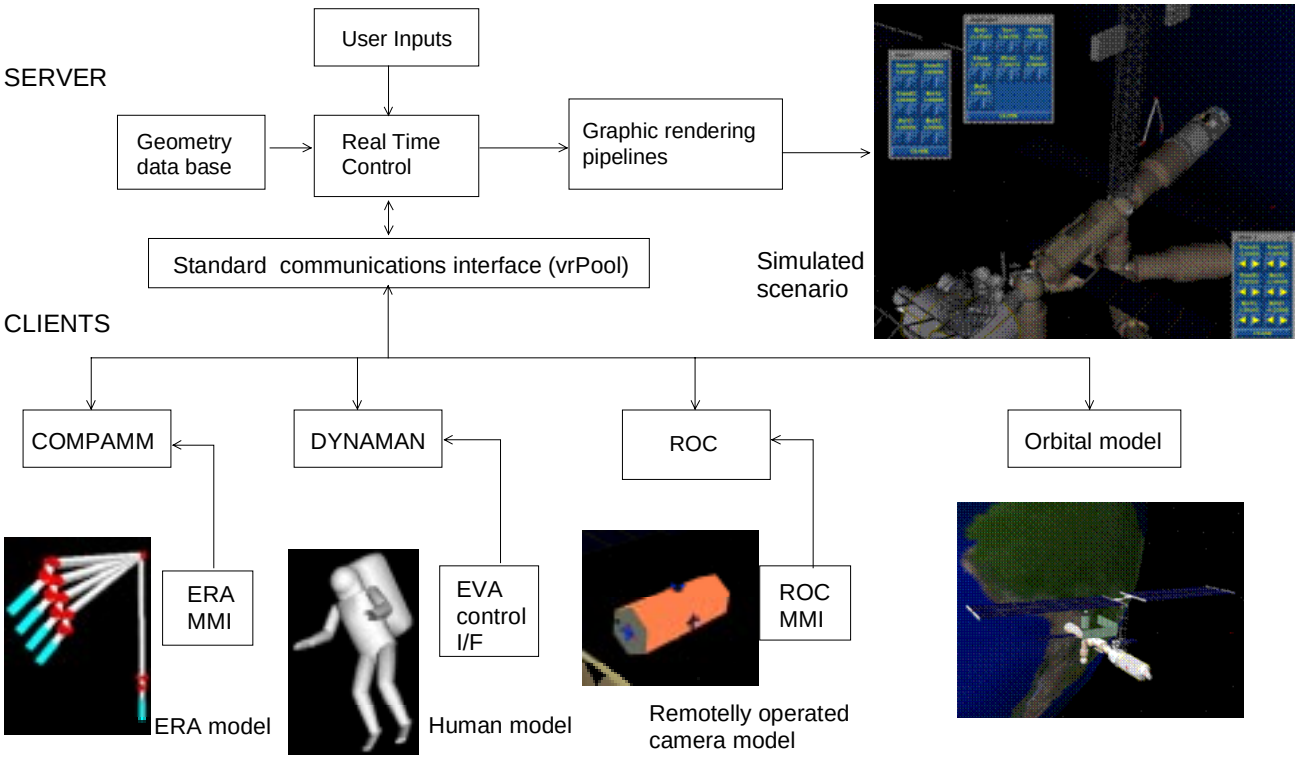

Figure 1. General architecture of the simulation system.

3 MODELING CAPABILITIES

One of the most interesting features of the simulation tool presented here is its capability of modeling complex scenarios built as an assembly of different individual components. These components can represent the behaviour of mechanical systems, form very simple ones like floating objects to more complex ones, such as robots or even the human body.

The space scenario is supposed to be moving in low earth orbit (LEO) and the motion of all its components is defined with respect to such a LEO. The basic data of the LEO (altitude, period,..) can be defined at the simulation level. This facilitates the modification of the LEO without requiring the modification of the individual components of the scenario.

The software tool includes a notion of the time, so as to bring to the different components a time value that allows them to define their exact location (i.e. planet motion). This allows the automatic inclusion of time effects such as day, night and eclipse. The micro gravity created

by the different spacecraft is also considered.

3.1 Spacecraft

Models of the International Space Station (ISS) are included, at three different stages of its construction process. Models of the MIR and the Shuttle spacecraft are also included.

3.2 Planets

The tool includes the possibility of modelling the motion of the planets, including the gravitational field they create and their appearance and influence in the scenario. The planet position and motion corresponds to the current value of the time provided by the simulation environment. The following planets are considered: earth, sun, and moon.

3.3 Remotely operated camera

The remotely operated camera (ROC) concept corresponds to a flying object that contains a camera and is controlled from a remote position (figure 2). For this purpose the Inspector concept, developed by Daimler Benz Aerospace[4], is used.

Two different models are available:

- A dynamic model, that includes the inertial properties as well as a dynamic model of the propulsion system. The motion of the ROC is carried out by applying to it the impulses originated in the thrusters, defined by the ignition time of each thruster.
- A simplified kinematic model, where the ROC is moved in a kinematic way by applying to it known increments of its position, with independence of the thrusts required for generating such motion. In this case the propulsion model is not considered.

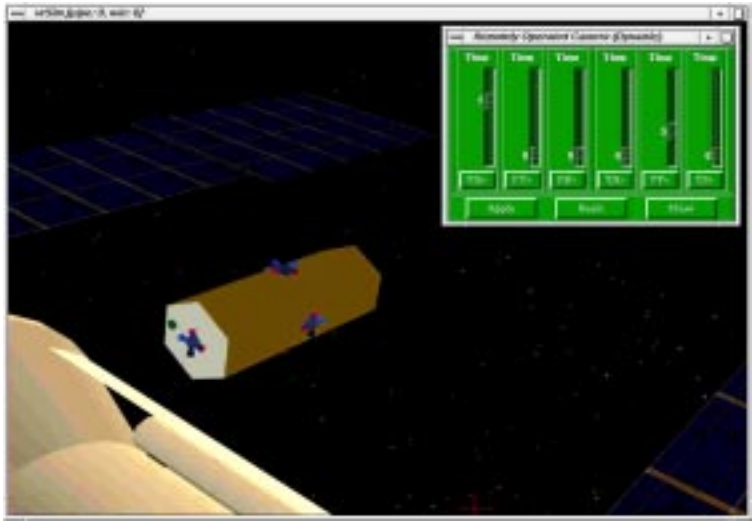

Figure 2. The remotely operated camera model.

3.4 Floating objects

The simulation tool gives the possibility of modeling flying objects. These are free objects floating in the space and behaving according to the laws of the orbital mechanics. Two types of forces can be applied to the flying objects: gravitational forces generated by the surrounding spacecraft and impulsive forces applied by the simulation user. Gravitational forces are applied to the flying objects automatically, as they are generated by the mass distribution of the other spacecraft. Impulsive forces are applied to the flying objects by the simulation user via a user interface. Two types of interfaces are considered:

- ◊ A conventional GUI based on Motif widgets. This GUI includes sliders to define the orientation of the force with respect to the object local reference frame and its value. An interface button is used to apply the force.
- ◊ A user interface based on a joystick, connected to the computer via a serial line. The joystick orientation defines the orientation of the force and an auxiliary button defines the force value. The joystick trigger is used to apply the force to the flying object.

The forces applied by the user are displayed in the graphic scenario as vectors whose orientation corresponds to the force orientation and whose length corresponds to the force value (figure 3).

It is possible to include many flying objects at the same time in the scenario, each of them with a separate GUI.

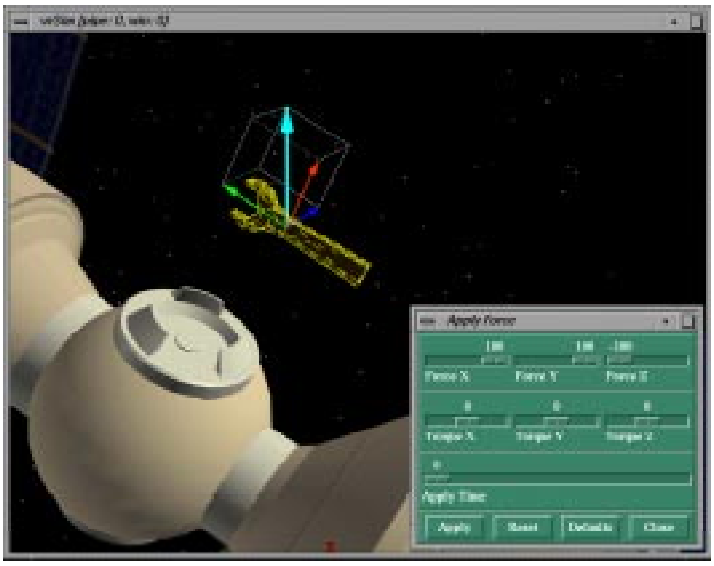

Figure 3. Virtual impulsive force applied to a floating object.

The definition of the forces (dynamic model) or known motion (simplified model) is carried out interactively, from within an appropriate interface based on Motif widgets. This interface appears on the screen of the ROC operator, which can be located in the main

workstation or in any other workstation that is connected to the network.

The ROC includes an associated graphical model made up of facets, so as to display it in the scenario. The effect of the degradation of the camera image originated by noise or flare is also considered by the visualization module.

3.5 Mechanical systems

The software tool includes the capability of modeling the behavior of complex mechanical systems. For this purpose the COMPAMM simulation program is used [6]. COMPAMM is a general purpose software for the kinematic and dynamic simulation of multibody systems, developed by CEIT. It can deal with a wide range of mechanical systems of open and closed loop nature, and its high performance algorithms make it suitable for real time applications where the time required to evaluate every new position of the mechanism must be kept under a maximum value (the integration time step).

The tool includes a model of the ERA robotic arm in its latest configuration[5], with two base elements and 6 degrees of freedom (figure 4). The ERA arm is controlled from within two different interfaces:

- ◊ The conventional COMPAMM interface, which is based on Motif and contains one widget for each robot angular degree of freedom.
- ◊ A virtual control box, which is located as a graphic object fixed in the scenario. The control box has a simple graphic representation of the different control elements (buttons) that control the robot and can be accessed from within the immersive interface by using the virtual pointer to push the different buttons.

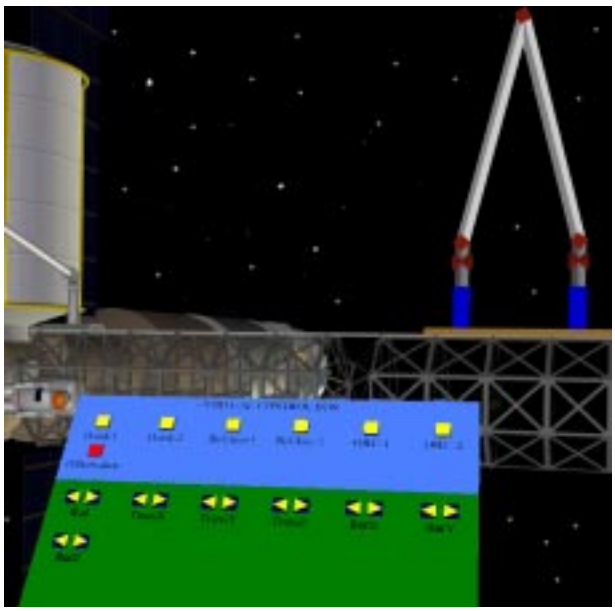

Figure 4. The ERA robot model with the virtual control box.

The ERA model has the possibility of grasping free objects located in the scenario, such as the Orbit Replacement Units (ORU). The selection of the object to grasp is made from within the ERA control interface. After the grasp the behavior of the model is updated accordingly.

3.6 Human body

The simulation tool includes the possibility of modeling the human body in EVA, and for this purpose the DYNAMAN tool is used. DYNAMAN is a real time kinematic simulation tool, developed by CEIT for ESA/ESTEC, oriented to the simulation of the motion of the human body in the space[7].

The human body models used correspond to the DYNAMAN models for EVA activities (figure 5), that are available in three different sizes: 5 minimum, 50 medium and 95 maximum. These models include the constraints imposed by the EVA suit and have 36 degrees of freedom that control 36 different angles of the body model, plus the 6 parameters used to define the absolute position.

The human body degrees of freedom are controlled by using a conventional interface, based on Motif, which can be located in the screen of an auxiliary workstation, to allow the control of the human model by a different user of the main user of the simulation tool.

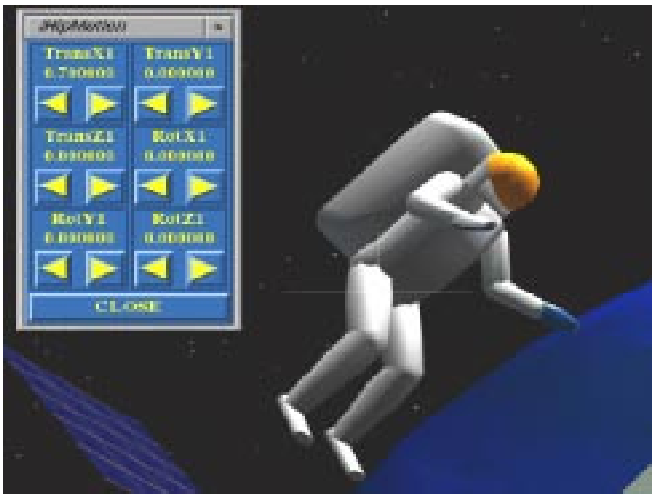

Figure 5. Human model in EVA.

4 VISUALIZATION

Tightly connected to the control system is a high performance visualization system, that generates a realistic 3D image of the scenario situation and system evolution, including effects such as the textures, local lights, earth reflected light, eclipse zones, sun flare, etc. It also provides collision detection among the different objects that make up the scenario.

The tool has the possibility of including detailed geometrical models of the different components. These geometrical models are used for the graphic output generated by the tool

and for other actions applied to the components such as picking or collision detection.

The light emitted by the sun is considered, as well as the light reflected by the moon and the earth.

5 VIRTUAL REALITY

The VR interface includes two levels of immersion: a fully immersive one, based on the use of a Helmet Mounted Display (HMD), and simplified one, based on stereo images (figure 6). The second one is used mainly for scenarios set up and debugging, as well as for simple simulations.

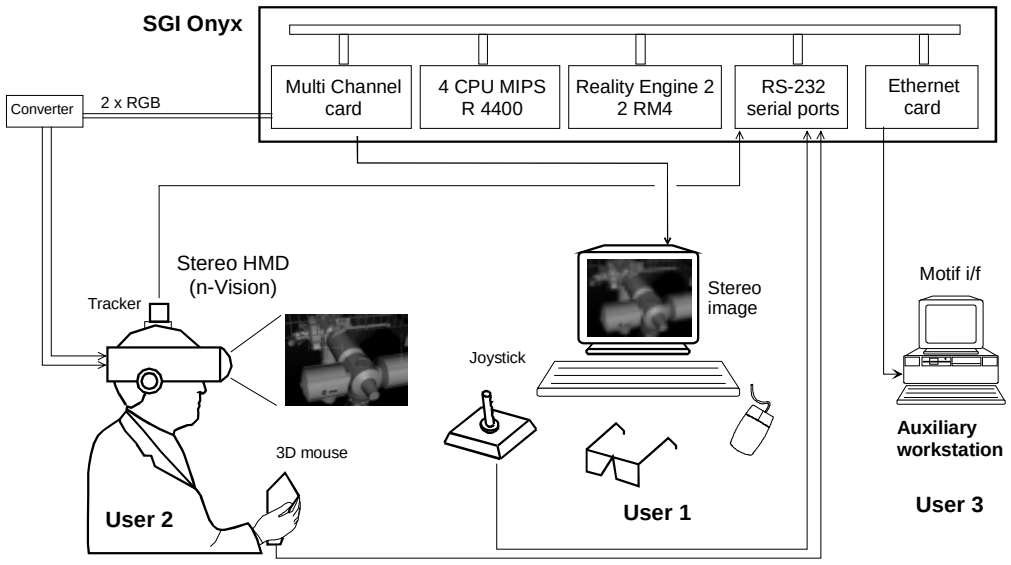

Figure 6. Virtual Reality interface and hardware architecture.

5.1 HMD immersive interface

This interface is based on the use of the HMD and a joystick[8]. The HMD represents a stereo image of the scenario and defines the viewing direction, which corresponds to the orientation of the sensor position of the HMD. The image shown on the HMD does not contain any Motif interface element that cannot be seen in detail in this type of devices.

The joystick allows performing the following actions.

- Move forward and backward by pressing one of the joystick switches. The motion is made in the current view direction, defined by the HMD orientation sensor.
- Move a virtual pointer on the scenario. The virtual pointer is a special 3D cursor that is displayed on the scenario. By using the virtual pointer the user can select one object of the scenario and apply an action to it. Aligning the virtual pointer with the graphic representation of the object and pressing a switch of the joystick will make the selection.

After that, an auxiliary menu will appear, containing all the actions supported by the object.

5.2 Stereo interface

This simplified interface is based on the use of a set of stereo glasses and the mouse. The simulation generates a stereo image of the scenario on the main workstation screen, and the mouse is used to interact with the system.

6 INTERACTIVE USER INTERFACE

The simulation tool includes an interface to allow the communication between the user and the system. This interface is displayed on the main workstation screen and is based in the combined use of the mouse and Motif widgets. It permits:

- Select the camera used to view the scene among all the cameras defined, including the ROC.
- Control the position and orientation of the viewer in the scenario, this is: to move the camera over it. For the ROC this is done by using its specific interface.
- Control the evolution of the simulation by sending the basic control actions: stop, start, freeze, resume, record and replay.
- Select one object of the scenario and apply an action on it. The selection is made by clicking with the mouse on the graphic representation of the object. After that, an auxiliary menu appears, containing all the actions supported by the object.

Some of the components of the scenario (ROC, floating objects, ERA, etc.) have their own Motif interfaces, described previously.

7 SIMULATION SCENARIOS

The simulation tool presented here has been used to build a large number of scenarios[9], by using the different models available, described previously. Two representative cases are presented here to show the potential of the tool.

7.1 ISSA inspection

The purpose of this scenario is to simulate the external inspection of the ISSA by means of a tele-operated camera, as can be seen in figure 7. The scenario contains a geometry model of the ISSA, a dynamic model of the tele-operated camera and a complete environment model, which includes free flying objects and models of the planets.

This scenario can be simulated either with a single user or by two users. In the first case only the stereo interface is used. In the second case the fully immersive interface with the HMD is used by user 1 and the stereo image is used by user 2.

The main functionalities provided to the users are:

- Move around the scenario as an external viewer, independently of the ROC position. This used mainly for monitoring the simulation process
- Control the motion of the ROC (user 1 or 2). This is used mainly for training the ROC

operator.

- Use the cameras attached to the ROC in order to view the scenario through them (user 1). This is normally used for evaluating the inspection process itself.

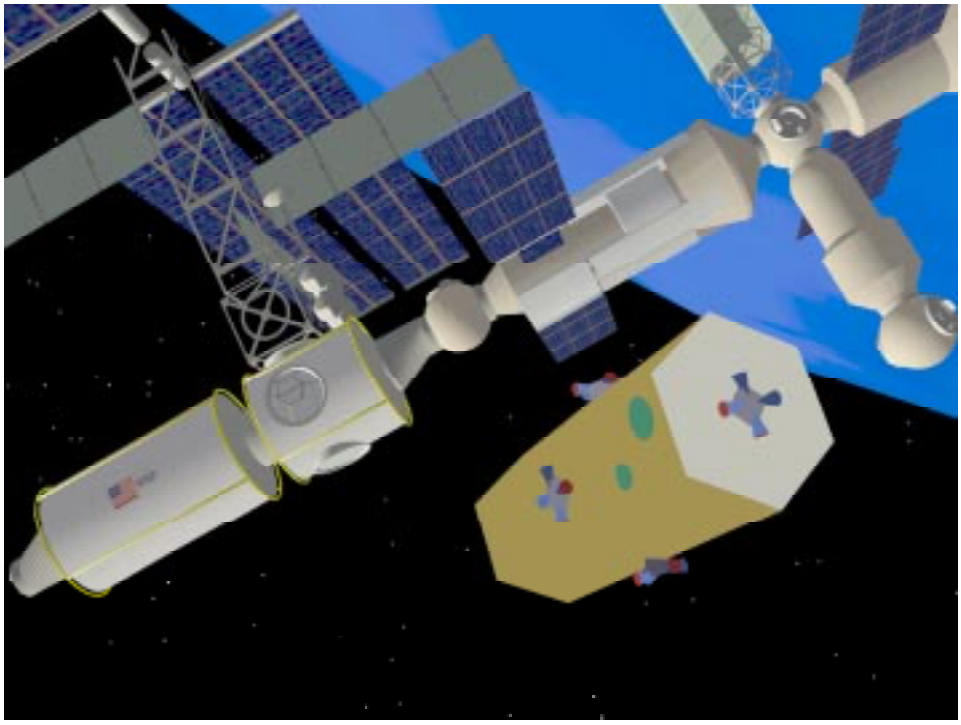

Figure 7. Simulation of the ISSA inspection using a tele-operated camera.

7.2 Combined ERA+EVA activity

This scenario contains a model of the ISSA in the final construction phase, including the ORUs, models of the planets, an two mechanical models: the ERA robotic arm, and a model of an astronaut in EVA.

The complexity of the complete scenario requires typically two simultaneous users on two workstations. User 1 is in fully immersion with the HMD and user 2 in the main workstation screen. The users can:

- Move around the scenario as an external viewer (user 1).
- Control the motion of ERA (user 1 via the ERA control box or user 2 via the Motif interface).
- Control the motion of the EVA model (user 2 via the Motif interface).

Figure 8 shows a general view of the scenario, as can be seen in the main console.

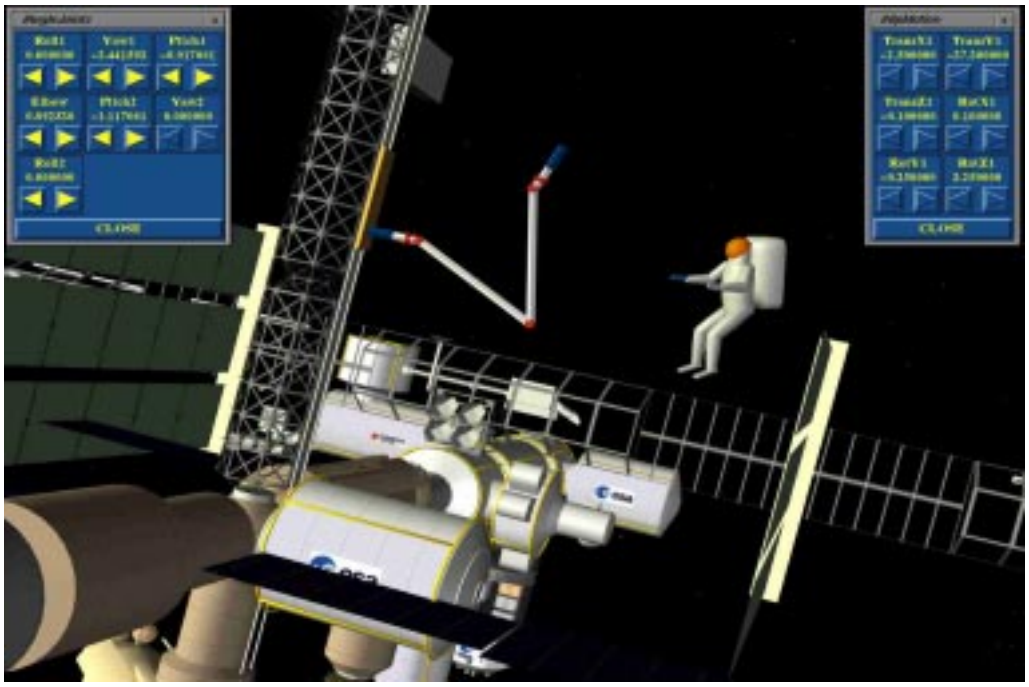

Figure 8. Combined ERA+EVA activity. Stereo view.

Figure 9 shows the use of the ERA model to simulate the assembly of an in-orbit replacement unit, as can be seen from within the HMD interface.

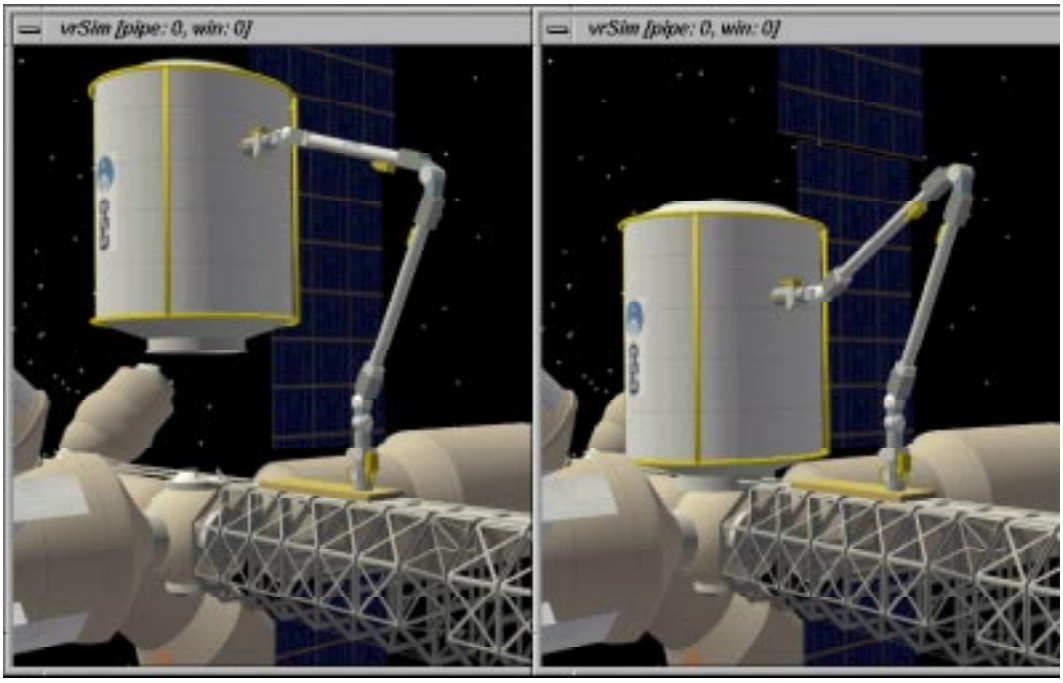

Figure 9. Mechanical assembly simulated with the ERA robot.

8 HARDWARE

The simulation tool requires as a minimum the use of a main workstation type Silicon Graphics Onyx with 4 CPU of type MIPS R10000 and 256 MB RAM. The graphic card is type Reality Engine 2 with two raster managers (type RM4) and 4 MB for textures. A Multi Channel Option card is used for video output, only if a HMD is used. The workstation runs under the IRIX 6 operating system, with Performer and REACT. Figure 6 shows the main hardware components.

Optionally an auxiliary workstation including an X server can be used, dedicated only to the different Motif interfaces.

This hardware is used for the simulation of the previously described scenarios with the performance specified. However, the application can also run with less powerful hardware when using simpler scenarios, with a lower performance. For example it is possible to run with less CPU, between 3 and 1 (of the MIPS R10000 type), keeping all the functionalities, and only decreasing the response time.

The application can also run with less powerful graphic cards, in this case only the functionalities allowed by the graphic card are available.

9 PERFORMANCE

The simulation tool runs in real time, using the IRIX REACT software. The number of frames generated per second depends on the complexity of the scenario, which is basically related to the graphic database (number of polygons, use of textures, partitioning, etc.) and the number and size of the mechanical systems (ERA and EVA models).

A frame rate of 15 frames/sec is normally enough for interactive simulation and can be reached with complex realistic scenarios, such as the ones described previously. A larger frame rate of 30 frames/sec can only be reached with simpler scenarios, including about 2000 polygons. Higher frame rates (60 frames/sec) can only be reached with more sophisticated hardware (more powerful graphic cards, multiple graphic pipelines, etc).

10 CONCLUSIONS

The tool presented allows the dynamic simulation in real time of complex space scenarios that include mechanical systems, from the early phases of the design of their components. The system has been designed as a general-purpose tool, allowing plugging in any simulation module by using a standard interface for data and events communications.

The tool includes simulation modules for orbital mechanics, planets motion, free flying objects and a remotely operated camera.

The tool has been connected to the DYNAMAN simulation program, giving the possibility of using models of the human body in the scenario. A model dynamic model of ERA is also included, created by using the COMPAMM multibody simulation program.

The tool includes a Virtual Reality interface that allows the user of the simulation tool to control most of the components of the scenario, while being immersed in it. The VR interface is based on the use of a HMD for fully immersion or a simple stereo image representation on

the computer screen, which is very useful for scenario set up and debug.

The simulation system has been used to build different realistic simulation scenarios, whose simulation reaches real time response, using graphic super workstations with multi CPU architecture and appropriate graphic hardware.

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